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FINAL REPORT ON GRANT NAGW-1535

1. PREAMBLE.

The grant entitled "The effects on the ionosphere of inertia in the high latitude neutral thermosphere" was originally submitted by Dr. F. G. McCormac (as P.I.) and Prof. T. L. Killeen (as Co. I.). In early 1990 Dr. McCormac left the U. S. to take up a lecturing position at Queens University in Belfast. At this time Prof. Killeen took over the role of P.I. and Dr. A. G. Burns was included as a Co. I. for this project. Much of the work described in this report was undertaken by Mr. W. Deng, under the supervision of Prof. Killeen and Dr. Burns. It will form the major proportion of Mr. Deng's Ph. D. thesis.

This report describes the progress that has been made by us in the last 3 years. The structure of this report is as follows: a brief synopsis of the original aims of the grant NAGW-1535 is given in the next section; then there is a summary of the scientific accomplishments that have occurred over the grant period; last, we make some brief concluding remarks. Reprints of articles that have recently appeared in refereed journals are appended to the end of this document.

1. INTRODUCTION: SCIENTIFIC BACKGROUND FOR NAGW-1535.

High-latitude ionospheric currents, plasma temperatures, densities and composition are all affected by the time-dependent response of the neutral thermosphere to ion drag and Joule heating through a variety of complex feedback processes. These processes can best be studied numerically using the appropriate non-linear numerical modeling techniques in conjunction with experimental case studies. In particular, the basic physics of these processes can be understood using a model, and these concepts can then be applied to more complex realistic situations by developing the appropriate simulations of real events. Finally, these model results can be compared with satellite-derived data from the thermosphere.

In the work described here we used numerical simulations from the National Center of Atmospheric Research Thermosphere/Ionosphere General Circulation Model (NCAR-

TIGCM) and data from the Dynamics Explorer 2 (DE 2) satellite to study the time-dependent effects of the inertia of the neutral thermosphere on ionospheric currents, plasma temperatures, densities and composition. One particular case of these inertial effects is the so-called “fly-wheel effect”. This effect occurs when the neutral gas, that has been spun-up by the large ionospheric winds associated with a geomagnetic storm, moves faster than the ions in the period after the end of the main phase of the storm. In these circumstances, the neutral gas can drag the ions along with them. It is this last effect, which is described in the next section, that we have studied under this grant.

3. SCIENTIFIC ACCOMPLISHMENTS.

In this project we have addressed the general scientific aims of the project that were mentioned above. The following results discuss our main achievements during the three year grant period.

Lyons et al. (1985) showed that the momentum associated with the neutral circulation at high latitudes can drive significant Hall current systems for up to 6 hours after the cessation of strong geomagnetic forcing - the neutral flywheel effect. In our original proposal we stated that we intended to investigate this effect more thoroughly by developing improved codes for the Hall and Pedersen currents. This computer program was to include the improvements associated with the changes in the NCAR-TIGCM in the last six years. We also proposed to use these results to study a set of simple model runs. The rationale for using simple runs was that by doing this we could simplify the physics associated with the flywheel effect, making it easier to understand. After making these simple runs, this technique could then be applied to more realistic cases that would allow us to compare the model results with data.

Improvements in the TIGCM that have immediate impact on this study are 1) the inclusion of neutral composition in the model and 2) the inclusion of an interactive ionosphere in the model, including self-consistent calculations of the Pedersen and Hall conductivities which use recent advances in knowledge about thermospheric neutral-ion collision frequencies, and the more realistic ionosphere calculated in the model. Most recently, Richmond et al. (1992) have developed a version of the TIGCM that includes the global dynamo. However, this version of the model is still experimental and was not available for use during the grant period.

In studying DE 2 data we found several periods which were, within themselves, sufficiently simple to provide significant insight into the physics associated with the flywheel phenomena. Therefore, we simulated these periods, rather than using the simple, unrealistic cases that we had originally intended to use. The principal results that came out of this work were:

- 1) Neutral winds contribute significantly to the ionospheric horizontal currents and field-aligned currents during periods of northward B_z .
- 2) The Hall currents that are driven by these neutral winds are in the opposite direction to those driven by the ions during southward B_z conditions.
- 3) The neutrals can contribute as much as 80% of the total polar Hall current system, and they may dominate for as long as 6 hours after the end of the main phase of the storm.

We extended the original modeling of the Hall and Pedersen currents to include field-aligned currents that were calculated using the Killeen et al. (1987) Vector Spherical Harmonic analysis (VSH) model. This VSH representation of the output from the TIGCM has allowed us to calculate the curl and divergence of the vector fields. We then used the relationship

$$J_{||} = -\nabla^2 \xi_p$$

to estimate the field-aligned current, $J_{||}$. The potential, ξ_p , can be calculated easily when the VSH representation is used. The principal results that we obtained from this work were:

- 1) Our calculations of the field-aligned currents during southward B_z conditions are in general agreement with observations.
- 2) The field-aligned currents driven by the neutral winds may make a contribution to the total field-aligned current system during northward B_z conditions, but our values of these currents appear to be too small to account for observations without invoking other mechanisms.

In addition to the work described above, we undertook some further studies using DE 2 data to confirm that such behavior does occur in the thermosphere. In general, we found reasonable agreement (see Deng et al., 1992) between modeled Hall currents and those calculated from data measured by the DE 2 satellite. However, agreement between modeled and observed field-aligned currents was not so good. This was a result of the large number

of uncertainties that are included in this calculation, both on the modeling side and in terms of the assumptions that are required to reduce the raw data into field-aligned currents. However, we did conclude that the DE 2 measurements provide support for the concept of flywheel effects, at least for "local" flywheel effects at satellite altitudes.

Also in connection with this grant, Burns and Killeen (1992) studied DE 2 data to investigate neutral composition effects in the immediate post-geomagnetic-storm period. They found that, after a relatively small storm, it took neutral composition about six or seven hours to recover from negative storm effects at high latitudes, while it took 10 to 18 hours at higher latitudes.

Killeen et al. (1992) have presented some of this material in a review. This review described the effect of neutral density changes on satellite orbits. As geomagnetic storms are responsible for some of the most important perturbations in the orbits of low-orbiting satellites, the recovery time for density in the immediate post-storm period is of great importance.

At the most recent AGU meeting Mr. Deng presented work on the dissipation of ionospheric currents in the thermosphere. In this work, he considered the partition of this energy dissipation between Lorentz forcing and Joule heating, and concluded that the latter was much more important than the former. He also studied the spatial distribution of the dissipation, and described how it varied with height and with location around the auroral oval.

4. CONCLUDING REMARKS.

In the four year period of NAGW-1535 we achieved most of the scientific goals that we described in our original proposal. During this time, several papers have been published which are connected with this grant. Reprints of two of these articles are included with this report. In addition, Mr. Deng's work on the flywheel effect has been the major thrust of his Ph. D. thesis, which he hopes to complete this year.

5. REFERENCES

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APPENDIX 1.

PUBLICATIONS DURING THE GRANT PERIOD.

- Burns, A. G. and T. L. Killeen, Changes of neutral composition in the thermosphere, *Adv. Astronaut. Sci.*, 3, 2295-2312, 1992.
- Burns, A. G. and T. L. Killeen, The equatorial neutral thermospheric response to geomagnetic forcing, *Geophys. Res. Lett.*, 19, 977-981, 1992.
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APPENDIX 2.

PRESENTATIONS GIVEN DURING THE GRANT PERIOD.

- "Post-storm recovery: a case study", A. G. Burns, T. L. Killeen and R. G. Roble, Spring AGU, Baltimore, 1991.
- "The effects of inertia on ionospheric currents in the high latitude neutral thermosphere", W. Deng, T. L. Killeen, A. G. Burns, F. G. McCormac and R. G. Roble, Spring AGU, Baltimore, 1991.
- "Contribution of the thermospheric neutral wind to high-latitude electrodynamics", J. P. Thayer, J. F. Vickery, T. L. Killeen, W. Deng, A. G. Burns and R. A. Heelis, IAGA, IUGG, Vienna, Austria, August 1991.
- "Prediction of density changes and winds affecting spacecraft trajectories", T. L. Killeen and F. A. Marcos, IUGG, Vienna, Austria, August 1991.
- "Thermosphere-ionosphere-magnetosphere coupling at high latitudes: ground based and satellite observations", T. L. Killeen, Fall AGU, San Francisco, December 1991.
- "Poynting flux in the polar thermosphere as derived from the Dynamics Explorer 2 satellite", W. Deng, T. L. Killeen, A. G. Burns and J. Slavin, Spring AGU, Montreal, 1992.